**PHSX 222L** $RC$ **Circuits** **Name:**______________________

Object: (a) To study the voltage-time relationship in a charging and discharging capacitor and to measure the circuit's time constant, $\tau$. (b) To use an $RC$ circuit with a neon bulb to measure the capacitance. (c) to study two special $RC$ circuits, the differentiator and the integrator.

Theory:

Charging and Discharging Capacitor, and $RC$: When a voltage source, a resistor, and a capacitor are connected in series, the voltage on the charging capacitor as a function of time is:

$$V_C(t) = V_0(1 - \mathrm{e}^{-t/RC}) = V_0(1 - \mathrm{e}^{-t/\tau}) \tag{1}$$

where $\tau = RC$ is called the time constant. In figure 1 the switch is set to position a.

If a previously charged capacitor is discharged through a resistor (switch set to position b in figure 1), the voltage during discharge is given by:

$$V_C(t) = V_0\mathrm{e}^{-t/RC} = V_0\mathrm{e}^{-t/\tau}. \tag{2}$$

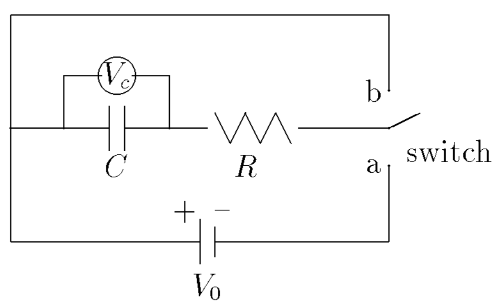



Figure 1: Circuit for a charging and discharging capacitor

Determining $C$ with a Neon bulb: When a voltage is applied to a neon bulb, no current will flow until the voltage has been increased to the point where the neon gas has become ionized. The ionizing voltage will be called $V_{\mathrm{on}}$. Once the gas has been ionized it will remain ionized and continue to conduct even though the applied voltage is somewhat reduced. The voltage at which the gas returns to its unionized state and at which the bulb ceases to conduct will be called $V_{\mathrm{off}}$ ($< V_{\mathrm{on}}$).

If a neon bulb is connected in parallel with the capacitor in an RC circuit powered by a voltage source as shown in figure 2, the voltage will gradually build up until the ionizing potential of the neon bulb is reached. At this point the bulb suddenly begins to conduct—thereby discharging the capacitor. This is seen as a brief flash in the bulb. After the discharge, the capacitor will begin to charge up again and another flash will occur. This process repeats over and over again causing the bulb to flash or blink at regular intervals. See problem P28.62 in Serway and consider our neon bulb as the voltage-controlled switch. The time between flashes $T$ can be calculated mathematically as follows:

$$V_C = V_0(1 - \mathrm{e}^{-t/RC}) \tag{3}$$

$$t = RC \ln\left(\frac{V_0}{V_0 - V_C}\right) \tag{4}$$

$$T = t_{\mathrm{on}} - t_{\mathrm{off}} = RC \ln\left(\frac{V_0 - V_{\mathrm{off}}}{V_0 - V_{\mathrm{on}}}\right). \tag{5}$$

This derivation assumes the resistance of the bulb when the Neon is ionized is zero; this is a good assumption; for a more complete derivation see my website.

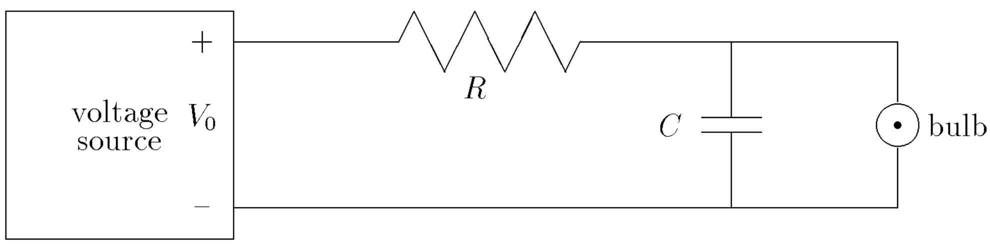



Figure 2: Circuit for determining $C$ with a Neon Bulb

<u>Two special circuits:</u>

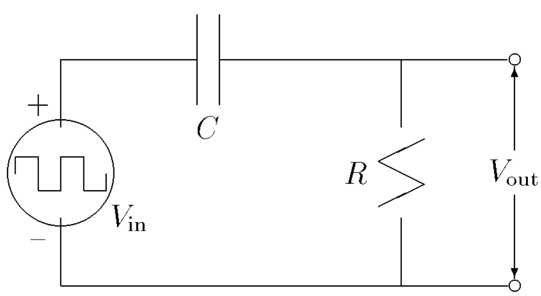



Figure 3: Differentiator

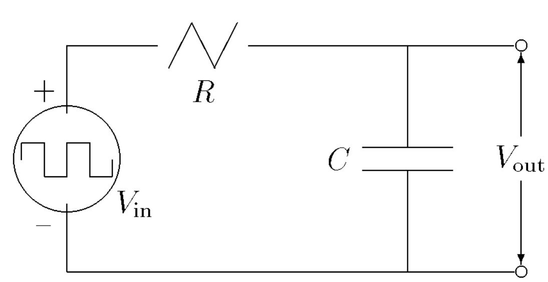



Figure 4: Integrator

The circuit in figure 3 is called an $RC$ differentiator because its output waveform approximates the mathematical derivative of the input function, *i.e.* $V_{\mathrm{out}}(t) \approx \mathrm{d}V_{\mathrm{in}}(t)/\mathrm{d}t$. The approximation is best when the period of the waveform is much larger than the circuit time constant ($T \gg RC$).

The circuit in figure 4 is called an $RC$ integrator because its output waveform approximates the mathematical integral of the input function, *i.e.* $V_{\mathrm{out}}(t) \approx \int V_{\mathrm{in}}(t)\mathrm{d}t$. The approximation is best when the period of the waveform is much smaller than the circuit time constant ($T \ll RC$).

Procedure: Use a breadboard to wire up the circuits (see my website for pictures and explanation).

Charging and Discharging Capacitor, and $RC$: Make sure your voltmeter has very high ($\geq 10$ M$\Omega$) internal resistance so as to not affect the circuit you are trying to observe.

1. Wire up an $RC$ circuit as shown in figure 1. Before turning on the voltage source, short the capacitor to make sure it is discharged. Set the power supply to 10–20 V. Use a capacitor of appoximately a hundred $\mu$F and a resistor of approximately a hundred k$\Omega$ so that $\tau$ is reasonable (say 10–20 seconds). If your $R$ is too big then the voltmeter will affect the circuit adversely, if it is too small then the time constant will be too small for easily measured data. Call $t = 0$ when you complete the circuit (equivalent to setting the switch to position a).

2. Monitor the voltage across the capacitor as a function of time. Plot your data, draw a smooth curve through your data, and on the same axes plot the curve given by equation 1. Draw a vertical dotted line at $t = \tau$ using the stated values for $R$ and $C$; how closely does it cross the curve at the point predicted by equation 1?

3. Remove the voltage source from the circuit (equivalent to flipping the switch to position b in figure 1 at $t = 0$) after the capacitor is charged.

4. Monitor the voltage across the capacitor as a function of time. Plot your data, draw a smooth curve through your data, and on the same axes plot the curve given by equation 2. Draw a vertical dotted line at $t = \tau$ using the stated values for $R$ and $C$; how closely does it cross the curve at the point predicted by equation 2?

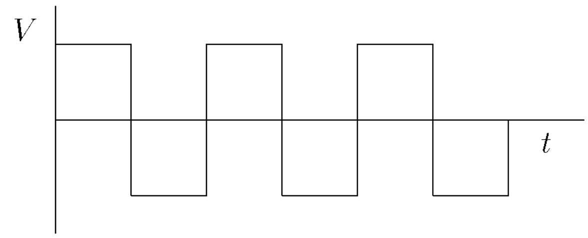
Determining $C$ with a Neon bulb:

1. First determine $V_{\text{on}}$ and $V_{\text{off}}$ directly without the capacitor in the circuit. Make sure you have at least a 10 k$\Omega$ current-limiting resistor in series with the bulb so as to not blow out the bulb. Use a voltmeter across the bulb to measure $V_{\text{on}}$ and $V_{\text{off}}$ as you slowly ramp up the voltage on your power supply, then back down again.

2. Connect up an $RC$ circuit with the neon bulb as per figure 2 ($V_0$ must be greater than $V_{\text{on}}$). Use a resistor with a large $R$, in the M$\Omega$ range, and a capacitor with $C$ in the $\mu$F range or slightly lower. Measure the period $T$ by counting the number of flashes in a given time ($T = 1/f$). From the period $T$, the resistance $R$, the applied voltage $V_0$, and the bulb voltages $V_{\text{on}}$ and $V_{\text{off}}$, calculate the value of the capacitance used in the circuit, and compare with the stated value. (For time periods that are too short to count visually, use an oscilloscope to display the waveform of the capacitor voltage. The period $T$ can be determined from the oscilloscope display.)

3. Repeat the previous procedure with two capacitors in series or in parallel to see if they obey equations 26.8 and 26.10 in Serway.

Two Special Circuits:




1. So you'll know what you are looking for on the oscilloscope, manually graphically differentiate and then integrate the square wave above *before* you consult Horowitz and Hill on my website.

2. Construct a differentiator following figure 3 with $R \approx 5$ k$\Omega$, $C \approx 0.1$ $\mu$F. Input a square wave (at about 50 Hz with $T \gg RC$) from the function generator and draw the output you see on the oscilloscope. Compare with the drawing you made previously.

3. Construct an integrator following figure 4 with $R \approx 1$ k$\Omega$, $C \approx 1$ $\mu$F. Input a square wave (at about 1000 Hz with $T \ll RC$) from the function generator and draw the output you see on the oscilloscope. Compare with the drawing you made previously.

Conclusions: